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NON-LINEAR BEHAVIOUR OF ION WAVES

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In this work we present experimental evidence concerning excitation of higher harmonics in the presence of an ion acoustic wave instability. This instability may be excited by electrons of the plasma having a shifted Maxwellian distribution[1] due to their drift motion.

We excite this instability in a magnetized argon plasma column. The schematic diagram of the experimental set-up is shown in figure 1. The plasma is produced by means of a hot-cathode K negatively biased, while grids G_1 and G_2 are kept at ground potential. Some of the plasma drifts into the equipotential volume between grids G_1 and G_2 forming a cylindrical column 2.2 cm in diameter and 4.7 cm long. The magnetic field is kept constant at 110G and is used only to confine the plasma and reduce the losses to the walls. The effect of the magnetic field on wave frequency was very small due to the changes in the plasma column diameter. For the production of the plasma we use argon gas at pressures $1\mu\,\mathrm{Hg} \leq p_A \leq 3\mu\mathrm{Hg}$. Our operating conditions are $n_0 \simeq 10^{11}\,\mathrm{cm}^{-3}$, $k_B\,Te \simeq 2\mathrm{eV}$. The measurements are performed by a double probe D. P.

The ion-acoustic-wave instability is excited by the drifting electrons in the plasma. The drift motion of the electrons is caused by the d. c. electric field, between the cathode and the grids, that drives an electron current through the plasma. Electron drift velocity is estimated to be about 4×10^6 cm/sec. Inside the volume between grids G_1 and G_2 the wave has to fulfill the boundary conditions imposed by grids G_1, G_2 and the cylindrical boundary of the plasma.

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20. Abstract This effort presents experimental evidence of the excitation of higher harmonics in the presence of an ion-acoustic wave stability. This instability was excited in an argon plasma column which was produced in a magnetic field of 110 Gauss. The pressure of the plasma was between 1 μm Hg and 3 μm Hg with an ion density of $10^{11} cm^{-3}$ and an electron temperature of 2 eV. The ion acoustic wave is excited by the drifting electrons in the plasma. The drift motion is the result of the D.C. electric field between the cathode and two grids which are kept at ground potential. The electron drift velocity was estimated to be 4×10^6 cm/sec. The low frequency oscillations were detected by a langmuir probe and analyzed by a panoramic spectrum analyzer. With cathode potential of 100v and 160v anode currents were 1.0 and 1.6A respectively. At 200v the anode current was 1.8A.

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The low frequency oscillations are detected by a Langmuir probe L. P. and they are analyzed by a panoramic spectrum analyzer.

Under certain discharge conditions, the ion-acoustic-wave instability becomes very strong and a number of modes are excited in the cylindrical plasma section. Figure 2(a) shows two typical photographs of our wave with weak $2(a_1)$ and strong $2(a_2)$ harmonic generation, under discharge conditions of a cathode potential of 100V and 160V and an anode current of 1A and 1.6A, respectively. By varying the driving current we can vary the amplitude of our wave and through this the weaker or stronger generation of the harmonics. So we have found that there is a critical value in the amplitude of our fundamental in the vicinity of which the amplitude of the harmonics increases very rapidly becoming comparable to the amplitude of the fundamental. Figure 2(b) shows a typical spectrum of such a case, analyzed by the spectrum analyzer, for discharge conditions of a cathode potential of 200V and an anode current of 1.8A.

By measuring with the Langmuir probe L. P. proper biased the d. c. and a. c. currents, we can find the $\left(\frac{\delta n}{n}\right)_m$ of the fundamental $(m = 1)$ and the harmonics $(m=2, 3, \ldots)$, taking $\left(\frac{\delta n}{n}\right)_m = \left(\frac{\delta i_m}{i_{dc}}\right)$. In figure 3 we have a plotting of $\left(\frac{\delta n}{n}\right)_m$ for $m = 2, 3$ and 4. versus $\left(\frac{\delta n}{n}\right)_1$. We can see that the critical value is something between $0.8 \lesssim \left(\frac{\delta n}{n}\right)_{1\ cr.} \lesssim 0.9$.

Making the assumption $T_i = T_{neutrals} \approx 300^\circ K$, at the operating pressures we have for the collision frequencies the following values: The ion-neutral collision frequency[2] is $4 \times 10^3 \sec^{-1} \leq \nu_{in} \leq 1.2 \times 10^4 \sec^{-1}$, and the electron-neutral collision frequency(3) is 3.0[illegible]$\times 10^6 \sec^{-1} \leq \nu_{en} \leq 9.06\times 10^6 \sec^{-1}$.

Under our operating conditions the electron drift velocity is large enough to overcome the collisional damping due to ion-neutral collisions, as well as the Landau damping which is negligible for $T_i \ll T_e$. Actually the imaginary part of the wave-number is given by the formula(4):

$$k_i \approx \frac{\nu_{in}}{2u_s} + \frac{\omega}{2u_s}\left(\frac{\pi}{2}\right)^{1/2}\left[\left(\frac{T_e}{T_i}\right)^{3/2} \exp\left(-\frac{T_e}{2T_i}\right) + \left(\frac{m_e}{m_i}\right)^{1/2}\left(1-\frac{u_d}{u_s}\right)\right]$$

where $u_s = \left(\frac{k_B T_e}{m_i}\right)^{1/2} = 2.2\times 10^5 \frac{cm}{sec}$ is the ion-sound velocity and u_d is the drift velocity along the direction of wave propagation, explaining the excitation of the ion-acoustic instability.
So, for $4\times 10^3 \sec^{-1} \leq \nu_{in} \leq 1.2\times 10^4 \sec^{-1}$ we find $-0.23 cm^{-1} \leq k_i \leq -0.21 cm^{-1}$.

Under our experimental conditions electron neutral collisions do not prevent the trapping of the electrons in the ion-acoustic wave completely, since $\omega_{Be} = \left[\left(\frac{m_i}{m_e}\right)\cdot\left(\frac{\delta n}{n}\right)\right]^{1/2}\cdot\omega$ is greater than $\nu_{eff} = \frac{1}{2}\left(\frac{k_B T_e}{e\phi_o}\right)\nu_{en}$ for $\frac{\delta n}{n} \geq 0.01$(5). Under these conditions one might expect that the instability would saturate when electrons were trapped by the ion-acoustic wave, and the distribution function was flattened over the region where the electrons were trapped(6). This saturation level is low enough and has been observed to be of the order of $\frac{\delta n}{n} \gtrsim 0.1$(7). But in our case this never happens and the electron distribution function does not flatten, so our wave continuously absorbs energy from the electrons and we have strong excitation of the ion-acoustic instability inside the cylindrical plasma section between grids G_1 and G_2 up to a level of $\delta n/n \approx 0.9$. The reason for this is due to the fact that in our case we have a standing wave. The component of the standing wave propagating in the direction from G_1 to G_2 interacts strongly with the streaming electrons and absorbs energy from them, while the other component propagating in the opposite direction gives less energy to the electrons such that the net balance is absorption of energy. On the other hand the streaming electrons interacting with the component of the standing wave propagating in the direction G_1 to G_2 terminate their interaction with the wave on the grid G_2 leaving the system before are completely trapped by the wave, while the latter is reflected back on G_2 and after a second reflection on G_1 interacts again with new electrons entering into the system through the grid G_1 and so on.

The most interesting part of the experiment is the above mentioned strong excitation of the ion-acoustic wave instability. Because of the strong excitation our initial wave steepens and breaks and strong harmonic generation occurs due to the mechanism of wave-wave interaction. This point has been considered in a recent work by Dawson et al[6]. They have showed that for perturbations, such that $\frac{\delta n}{n} \approx (k \cdot \lambda_D)^2 = 3.95 \times 10^{-4}$, propagating in a collisionless cold-ion plasma strong harmonic generation occurs. They have also showed that when $\frac{\delta n}{n} > 0.5$ ion trapping takes place. Thus, we have excitation of sideband waves due to the oscillations of the ions in the potential trough of the large amplitude ion-acoustic wave. Since now $\omega_{Bi} = \left(\frac{e E_o k_o}{m_i}\right)^{1/2} \left(\frac{\delta n}{n}\right)^{1/2} \cdot \omega$ then for $\left(\frac{\delta n}{n}\right) \simeq 0.9$ we have $\omega_{Bi} = 0.95\omega$, which means that for very strong excitation of the fundamental the sideband waves must be very close to the harmonics. This effect gives an explanation to the abrupt rising of the harmonics as $\delta n/n$ approaches unity since the bounce frequency approaches the fundamental and the side band frequencies coincide with the favored eigen frequencies of the cylindrical plasma section.

This work was presented by Mr. N. Karatzas at APS Meeting (Plasma Physics Division) held in Philadelphia, USA 31 October-3 November 1973).

Figure Captions

Figure 1	Experimental arrangement
Figure 2(a)	Typical photographs of our wave with weak harmonic generation ($2a_1$) and strong harmonic generation ($2a_2$).
2(b)	Typical spectrum with very strong harmonic generation.
Figure 3	The amplitude of the harmonics $(\frac{\delta n}{n})_m$ ($m = 2, 3, 4$) versus the amplitude of the fundamental $(\frac{\delta n}{n})_1$.

References

1. D. Phirsch, Low Frequency Waves and Irregularities in the Ionosphere (D. Reidel, Dordrecht, Holland, 1969), p. 1. B.D. Fried and R.W. Gould, Phys. Fluids 4, 139 (1961).
2. I. Alexeff and R.V. Neidigh, Phys. Rev. 129, 516 (1963).
3. B.S. Tanenbaum, Plasma Physics (McGraw-Hill, New York, 1967), pp. 252, 253, 348.
4. H.N. Ewald, F.W. Crawford, S.A. Self, Phys. Fluids 12, 303 (1969).
5. K. Nishikawa, C.S. Wu, Phys. Rev. Lett. 23, 1020 (1969).
6. J.M. Dawson, W.L. Kruer, B. Rosen, Princeton University, Plasma Physics Laboratory Report, MATT-883 (1972).
7. A.Y. Wong, B.H. Quon, B.H. Ripin, Phys. Rev. Lett. 30, 1299 (1973).

FIG.1. Experimental arrangement

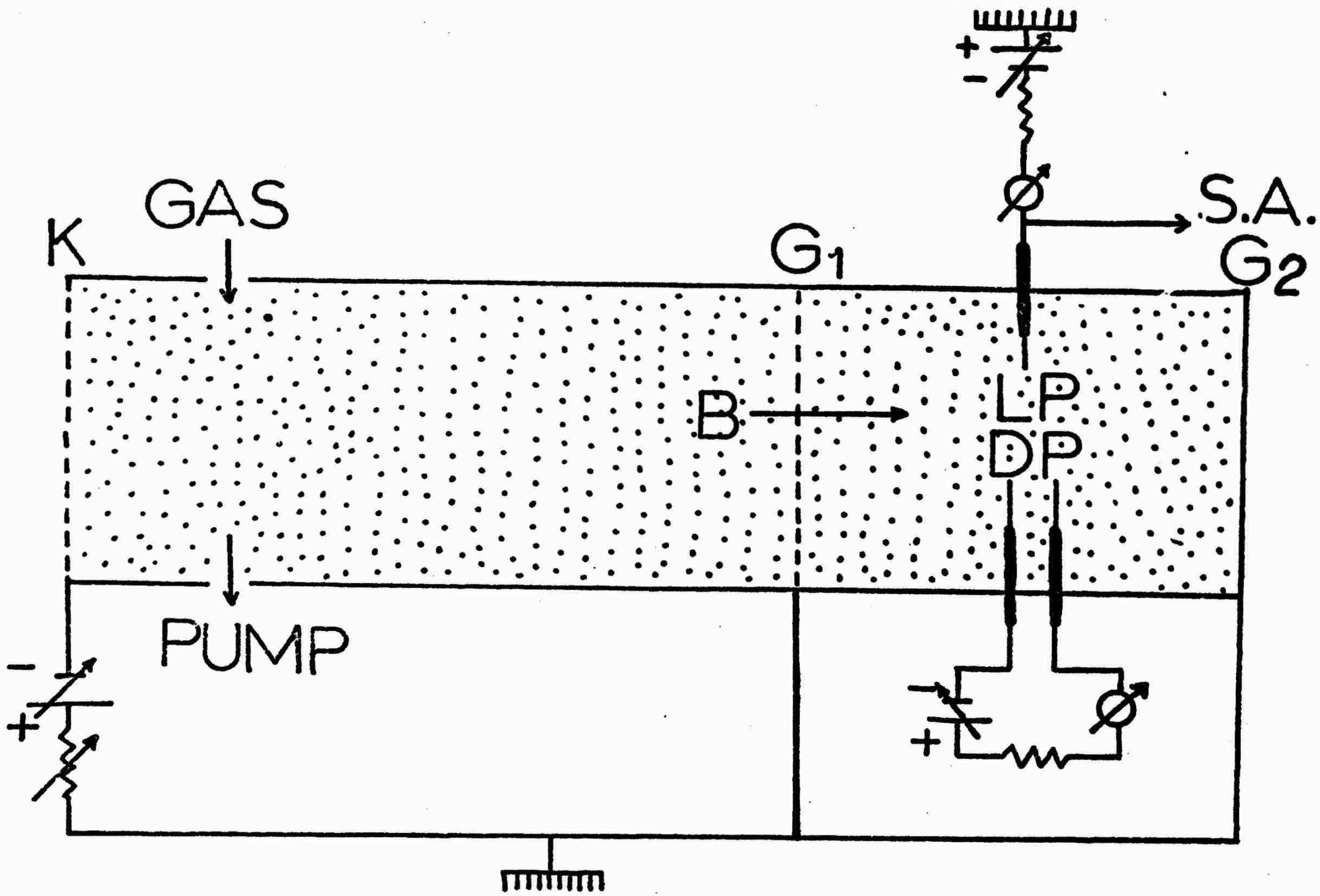


Fig. 2

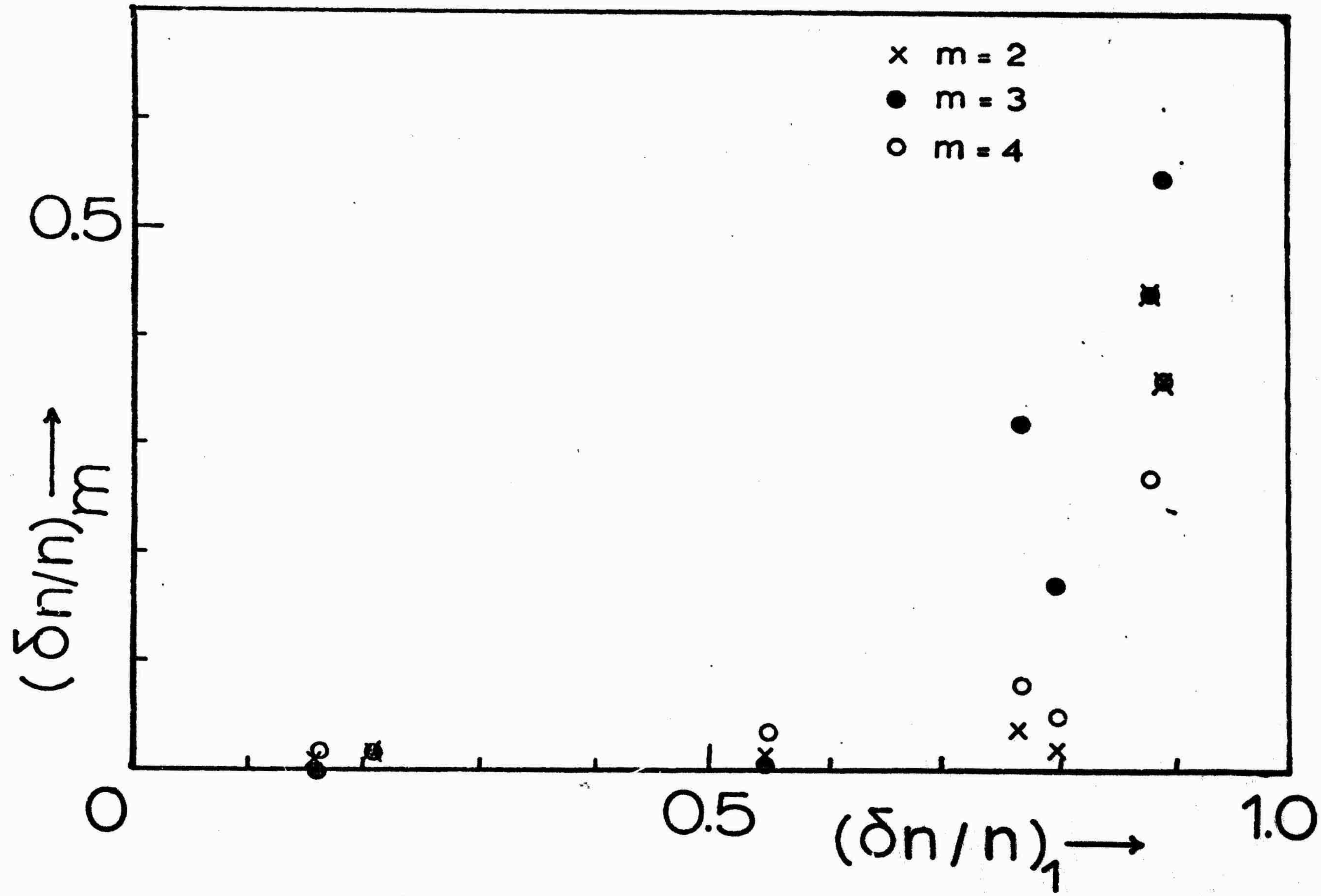
(a)

a1

a2

(b)

FIG.3



Microwave Generated Plasma (Modified Q-Machine)

A microwave generated plasma has been developed and set into operation very recently.

The plasma is generated by a microwave generator operating at 2.4 GHz and maximum power output 120 watts. The plasma is confined by a highly stabilized magnetic field set properly so that the electron cylotron frequency to be on/or near the microwave generator frequency. The coupling of the microwave power with the plasma is performed through a coil or a coaxial line according to the experimental requirements. The achieved coupling reaches 90%.

As working gases we have used Argon or Helium and the achieved plasma densities are about 10^{11} particles/cm^3, while electron temperatures of a few eV have been measured. The length of the plasma column is about 130 cm and the density is quite uniform over a cross-sectional area of 3 cm in diameter.

The plasma seems to be quiet [illegible] the [illegible] with the exception of some low frequency waves observed near the ion cyclotron harmonics under certain controlled conditions.

The operating pressures are about 10^{-5} Torr and the ion-neutral and electron-neutral collisions are of the order of $\nu_{in} \approx 40\ sec^{-1}$ and $\nu_{en} \approx 3x10^4 sec^{-1}$ respectively. The machine is particularly useful for the study of non-linear phenomena connected with ion-waves which consists the main activity of our laboratory.

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